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The Effects of the Environment on Iron and Zinc Concentrations and Performance of Common Bean (*Phaseolus vulgaris* L.) Genotypes

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Abstract: The common bean (*Phaseolus vulgaris* L.) is an important source of protein and minerals. It supplies all of the iron that humans require for metabolism and provides 25% of the daily requirements of magnesium and copper as well as 15% of potassium and zinc. The objective of this study was to determine the influence of the environment on iron and zinc concentrations and the performance of common bean genotypes. The experiments were conducted in the horticulture units at the Sokoine University of Agriculture (Morogoro) and Madiira-Arusha. A randomized, complete block design with three replications was used for 20 common bean genotypes. The leaves and seeds were collected at early flowering and at maturity and analyzed for iron and zinc concentrations, respectively. Several yield characteristics were measured, including the time required to reach 50% flowering and 85% maturity, the number of seeds to pod ratio, the number of pods to plant ratio, the 100 seed weight and the seed yield. Data analysis was performed using ANOVA and the mean was separated by Duncan's multiple range test and correlation techniques. The tested genotypes exhibited significant ($p<0.05$) differences in iron and zinc concentrations in the leaves and seeds of plants from both locations, with plants from Madiira-Arusha having the largest differences. The leaves showed higher levels of iron and zinc than the seeds. We observed a correlation between the concentration of Fe and Zn in both leaves and seeds ($r = 0.507^{***}$ and $r = 0.495^{*}$, respectively). In addition, there were significant differences ($p<0.05$) in the yield characteristics between genotypes of plants from both locations. These results suggest that environmental effects play a role in genotype levels of Fe and Zn in both leaves and seeds.

Key words: *Phaseolus vulgaris* L. iron, zinc, yield components

INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) is an important source of minerals and protein for many vegetarians and inhabitants of Latin America and Africa and in particular Tanzania (Moraghan and Grafton, 2001; Hillocks *et al*., 2006). It is estimated that over 75% of rural households in Tanzania depend on common beans for daily sustenance (CIAT, 2008). Bean production is concentrated in densely populated eastern Africa and the highlands of Southern Africa (Beebe *et al*., 2000). The common bean can supply all of the iron that humans require for metabolism (De Arunjo *et al*., 2003) and provides 25% of the daily requirements of magnesium and copper as well as 15% of the requirements for potassium and zinc (Beebe *et al*., 2000). Iron and zinc are essential micronutrients that are needed in small amounts for adequate human nutrition. Both of these minerals are critical to human well-being and an adequate supply of iron and zinc helps to prevent iron deficiency anaemia and zinc deficiency as well as other health problems of the developing world (Blair *et al*., 2009).

There are agronomic advantages to growing micronutrient-dense crops, including an efficiency in the uptake of minerals from the soil, which improves disease resistance in plants and results in a decrease for the need of fungicides (Graham *et al*., 1999). Therefore, breeding plants to select for micronutrient efficiency can enhance resistance to root diseases, which had been previously unattainable, as well as reduce the dependence on fungicides. The roots of plant genotypes that are efficient in mobilizing nutrients from surrounding soil are better able to penetrate and make use of the moisture and minerals contained in subsoils. These qualities are also associated with greater seedling vigor resulting in higher crop yields (Rengel and Graham, 1995). In nutrient-poor soils, there may not be sufficient seed reserves to last while additional roots develop in order to compensate for

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the low mineral supply (Bouis *et al*., 2000; Genc *et al*., 2000). Therefore, different genotypes can be tested in various environments to select for those with optimal growth characteristics.

The term environment relates to the set of climatic, soil, biotic (insect pests and diseases) and management conditions in an individual trial that are carried out at a given location (Gebeyehu and Assefa, 2003). When cultivars are compared in different environments, their performance relative to each other may not be the same. One cultivar may have a higher yield in some environments, while other cultivars may excel in others. Changes in the relative performance of genotypes across environments are referred to as genotype x environment interactions (Falconer and Mackay, 1996). The presence of a genotype x environment interaction automatically implies that the behavior of the genotypes depends upon the particular environment in which they are evaluated. The performance of genotypes grown in different environments relative to each other may be inconsistent and these inconsistencies result in changes to the ordering of genotypes from one environment to the next (Falconer and Mackay, 1996). Information on genotype x environment interactions is important to plant breeders for the development, selection and recommendation of cultivars that are suitable for growth in different environments. The objective of this study was to determine the influence of environments on the levels of iron and zinc as well as yield characterisitcs in common bean genotypes.

MATERIALS AND METHODS

Site: Experiments were conducted concurrently at two locations: at Sokoine University of Agriculture (SUA)-Morogoro (latitude 6°45°S, longitude of 37°40'E and altitude of 547 m above sea level (masl)) and at Madiira-Arusha (03°22'S, 36°48'E and 1248 masl), in Tanzania from September 2006 to January 2007. A Randomized, Complete Block Design (RCBD) was used with 20 treatments (bean genotypes) replicated three times. The selected bean genotypes were as follows: 35% had large seeds (40-45 g/100 seeds), 50% had medium seeds (25-40 g/100 seeds) and 15% had small seeds (less than 25 g/100 seeds) (Table 1). Before planting, soil samples were taken at both locations for soil analysis in order to determine the proper soil amendments needed.

Agronomic/field practices: Site clearing was done manually followed by harrowing. Phosphorus was applied to the soil before sowing in the form of triple super phosphate at a rate of 25 kg P ha^{-1}. Nitrogen was applied in the form of urea at a rate of 40 kg N ha^{-1} two weeks after emergence. Zinc was applied in the form of zinc sulphate at a rate of 5 kg Zn ha^{-1} before planting. The Zn was added, despite a sufficient amount at both sites, since application of P may have inhibited the availability of Zn. Two seeds were sown per hill at a spacing of 50×20 cm. After emergence, irrigation was carried out regularly to maintain the moisture content at or above field capacity. Four weedings were performed throughout the study and diseases and insect pests were controlled regularly using appropriate pesticides.

Plant sampling and analysis: At early flowering (10% flowering of the whole plant), trifoliolate leaves were sampled randomly from 10 plants per row in a plot and oven dried at 70°C. The samples were finely ground using a cyclone mill (Cyclotec Sample Mill 1093, Hoganas, Sweden) with a 1 mm mesh screen. At maturity, each row was harvested and the pods were threshed manually. The seeds were sun dried, winnowed and packed in paper bags. The seeds were then ground using a sample rotating mill and sieved through 1 mm mesh for Fe and Zn quantification. The Fe and Zn concentrations in the leaves and seeds were analyzed using standard procedures previously described (AOAC, 1995). The number of pods per plant, number of seeds per pod and 100 seed weight were measured.

Data analysis: All data were subjected to Analysis of Variance (ANOVA) using the MSTAT-C statistical package. Duncan's New Multiple Range Test (DNMRT) was used for mean separation. Simple linear correlations between seed Fe concentration and 100 seed weight, the Fe concentration in leaves and seeds and the Zn concentration in leaves and seeds were performed.

Table 1: Common bean genotypes used in the experiment

Variety	Source	Status	Seed size
Pesa	Morogoro	Improved	Medium
Bwana shamba	Arusha	Local	Large
Wanja	Mbeya	Local	Medium
Red wolaita	Arusha	Local	small
Canadian wonder	Morogoro	Local	Small
Mwanga chuchu	Kagera	Local	Small
Rosekoko	Kagera	Local	Large
Ranjonomy	Arusha	Line	Large
Mshindi	Morogoro	Improved	Medium
Lingot Blanc	Arusha	Line	Large
Uyole 94	Mbeya	Improved	Medium
Uyole 84	Mbeya	Improved	Medium
SUA 90	Morogoro	Improved	Medium
Jesca	Arusha	Improved	Medium
Selian 97	Arusha	Improved	Large
Rojo	Morogoro	Improved	Medium
Uyole 98	Mbeya	Improved	Medium
Lyamungu 90	Arusha	Improved	Large
Uyole 96	Mbeya	Improved	Large
Uyole 90	Mbeya	Improved	Medium

RESULTS AND DISCUSSION

The physical and chemical properties of the soil obtained from SUA-Morogoro and Madiira-Arusha are presented in Table 2. The data showed that the pH was optimum for bean production. The nitrogen content in the soil obtained from SUA-Morogoro and Madiira-Arusha was low and moderate, respectively and the P concentration was moderate at both sites. These findings implied that the soils had a moderately sufficient concentration of P in comparison to that previously described (Landon, 1991). The concentration of Zn extracted from the soil with diethylene triamine pentaacetic acid (DTPA) from the SUA Morogoro and Madiira-Arusha locations was 1.86 and 4.47 mg kg^{-1}, respectively. Landon (1991) has previously suggested that the critical level of Zn for plant growth is in the range of 0.5-1.0 mg kg^{-1}. Therefore, the concentration of Zn at both sites was found to be sufficient. In addition, the concentration of Fe extracted from the soil from both sites with DTPA was high and also found to be at a sufficient level for plant growth (Landon, 1991).

Iron and zinc concentration in leaves and seeds: At both locations, the differences in Fe concentration among the genotypes in both the seeds and leaves were significant ($p \leq 0.05$; Table 3). The concentration of Fe in the leaves was generally higher than the concentration in the seeds, suggesting that plant mineral concentrations vary between plant tissues. For example, genotype Jesca had the highest concentration of Fe in the leaves (997.9 ppm) and the lowest concentration in the seeds (33.4 ppm) compared to all other genotypes tested at Madiira-Arusha. Conversely, genotype Lingot blank had the lowest iron concentration in the leaves compared to all other genotypes at both locations. In Morogoro, Uyole 90 had the highest leaf iron concentration (700.4 ppm). The concentration of Fe in the seeds from genotypes grown in Morogoro was highest in Pesa (89.1 ppm), while the highest concentration of Fe in seeds from genotypes grown in Arusha was recorded in Mshindi (87.4 ppm). In contrast, the overall concentration of Fe in the seeds was slightly higher in genotypes grown in Morogoro than in Madiira-Arusha. Mshindi had the highest concentration of Fe in the seeds (79.7 ppm) among all of the genotypes, while Jesca had the lowest concentration (37.0 ppm) (Table 3). However, the combined analysis of variance from the two locations showed a significant variation in Fe concentration among the varieties at both locations (Table 3; $p \leq 0.05$). Genotypes and genotype x environment interaction components were not significant (Table 5).

The Zn concentration in the leaves and seeds varied significantly among bean genotypes at different sites (Table 4; $p \leq 0.05$). The mean Zn concentration in seeds was 23.4 and 22.8 ppm for the Morogoro and Madiira-Arusha locations, respectively. The concentration of Zn in the leaves was higher than that in the seeds at both locations. These results suggest that plant mineral concentrations vary between plant tissues (leafy structures vs. seeds). With regard to the locations, genotypes grown at Madiira-Arusha had higher Zn concentrations in both the leaves and seeds than those grown in Morogoro. The Zn concentrations in genotypes grown in Madiira-Arusha ranged from 21.8 to 30.2 ppm in the leaves and 17.1 to 32.0 ppm in the seeds (Table 4). However, the levels of Zn in the seeds were fairly low (22.8-23.4 ppm) compared to the levels in leaves (25-150 ppm), which was within a sufficient range for mature leaves (Landon, 1991). The results from the combined analysis of variance for plants grown in Morogoro and Madiira-Arusha showed a significant variation between the genotypes for the concentration of Zn in the seeds ($p \leq 0.05$). Genotypes x environment interactions were not statistically different. There was

Table 2: Physical-chemical characteristics of the experimental soils

Soil character and its unit	Madiira-Arusha	Rating/remarks	SUA-Morogoro	Rating/remarks
pH in water	6.99	Medium	7.33	High
Organic carbon (%)	2.73	High	1.55	Medium
Total N (%)	0.23	Medium	0.13	Low
Bray-1-P (mg kg^{-1})	29.79	Medium	40.14	Medium
CEC (cmol(+)/kg)	35.2	High	25.8	High
Exchangeable Ca (cmol(+)/kg)	16.8	High	7.42	Medium
Exchangeable Mg (cmol(+)/kg)	2.99	Medium	3.55	High
Exchangeable K (cmol(+)/kg)	2.07	Very high	0.985	Medium
Exchangeable Na (cmol(+)/kg)	1.111	High	0.514	Medium
DTPA Fe (mg kg^{-1})	71.54	very high	55.44	very high
DTPA Zn (mg kg^{-1})	4.47	Very high	1.855	High
Particle size analysis				
Sand (%)	28		71	
Silt (%)	31		11	
Clay (%)	41		18	
Textural class	Clay loam		Sand clay	

Table 3: Mean iron contents in leaves and seeds of common bean genotypes (ppm)

	Morogoro		Madiira-Arusha		Combined mean	
Genotypes	Leaves	Seeds	Leaves	Seeds	Leaves	Seeds
SUA90	482.2ab	46.8 bc	646.6abc	61.6ab	565.9bc	54.2abc
Jesca	545.0ab	40.6 bc	997.9a	33.4b	771.4ab	37.0c
Rojo	362.9b	67.2abc	660.0abc	53.9ab	511.5c	60.5abc
Lingot blanc	328.8b	54.0abc	392.4c	54.9ab	360.6c	54.5abc
Canadian wonder	508.6ab	61.5abc	686.9abc	53.0ab	596.3bc	57.2abc
Pesa	558.9b	89.1a	611.5bc	44.1ab	485.2c	71.1ab
Lyamungu 90	559.7b	81.9ab	626.0abc	41.5ab	492.9c	61.7abc
Mwanga chuchu	451.2ab	73.6abc	716.3abc	47.8ab	583.8bc	60.7abc
Mshindi	418.7ab	72.0abc	607.6bc	87.4a	513.1c	79.7a
Wanja	503.5ab	70.4abc	587.3bc	59.7ab	545.4bc	65.1abc
Ranjonomby	341.5b	54.0abc	539.5c	41.5ab	440.5c	47.8ab
Selian 97	345.1b	56.3abc	580.6bc	60.7ab	462.8c	58.5abc
Uyole 96	466.5ab	44.3bc	679.7abc	59.9ab	573.1bc	52.1abc
Bwana shamba	411.8ab	59.2abc	680.8abc	55.6ab	546.3bc	57.4abc
Rosekoko	350.3b	76.7abc	671.7abc	50.9ab	511.0c	63.5abc
Uyole 90	700.4a	58.1abc	950.4ab	64.2ab	825.4a	61.1abc
Red wolaita	389.9ab	65.7abc	695.2abc	50.9ab	542.5bc	58.3abc
Uyole 98	376.1ab	60.4abc	449.9c	52.5ab	413.0c	56.4abc
Uyole 94	461.1ab	34.0c	504.3c	60.3ab	482.7c	47.2bc
Uyole 84	382.5ab	41.1bc	689.9abc	47.2ab	536.2bc	44.1bc
Mean	427.1	60.8	648.9	54.1	538.0	57.4
CV%	39.5	38.7	29.7	31.2	33.7	35.7
SE±	97.4	13.6	111.3	9.7	50.3	3.3

Means followed by the same letter (s) are not significantly different according to DNMRT ($p \leq 0.05$)

Table 4: Mean Zn concentration (ppm) in leaves and seeds of common bean genotypes

	Morogoro		Madiira-Arusha		Combined mean	
Genotypes	Leaves	Seeds	Leaves	Seeds	Leaves	Seeds
SUA90	20.0abc	19.4c	29.2ab	22.7ab	24.6a	1.1abc
Jesca	23.8abc	24.7bc	22.8ab	24.0ab	23.3a	24.1abc
Rojo	20.7abc	18.4c	25.4ab	20.5ab	23.1a	19.5 bc
Lingot blanc	22.5abc	22.6bc	24.8ab	21.0ab	23.6a	21.8abc
Canadian wonder	21.1abc	21.7bc	28.7ab	17.1 b	24.7a	19.4 bc
Pesa	22.2abc	19.7c	22.2b	20.2ab	22.2a	20.0 bc
Lyamungo 90	28.2a	17.6c	21.7b	23.1ab	25.0a	20.4 bc
Mwanga chuchu	19.4abc	23.8bc	24.0ab	31.9a	21.7a	27.9ab
Mshindi	16.5c	16.9c	27.1ab	18.2 b	21.8a	17.5 c
Wanja	20.5abc	22.0bc	27.6ab	21.1ab	24.0a	21.5abc
Ranjonomby	23.4abc	22.4bc	27.3ab	20.8ab	25.4a	21.6abc
Selian 97	23.4abc	23.2bc	25.7ab	27.2ab	24.6a	25.2abc
Uyole 96	22.2abc	24.2c	24.7ab	21.3ab	23.4a	22.7abc
Bwana shamba	18.7bc	19.8c	27.4ab	27.3ab	23.6a	23.6abc
Rosekoko	22.4abc	23.4bc	25.4ab	20.1ab	23.9a	21.7abc
Uyole 90	26.3ab	24.5bc	27.5ab	28.3ab	26.9a	26.4ab
Red wolaita	21.0abc	37.3c	27.4ab	21.2ab	24.2a	29.2a
Uyole 98	22.2abc	32.9ab	30.2a	26.0ab	26.2a	29.5a
Uyole 94	16.4c	26.0ab	25.3ab	19.7 b	20.9a	22.8abc
Uyole 84	19.3abc	26.7bc	28.7ab	24.2ab	20.9a	25.4abc
Mean	21.6	23.4	26.2	22.8	23.9	23.0
CV%	22.0	25.5	15.3	26.5	18.4	26.2
SE±	2.7	3.4	2.3	3.6	NS	2.0

Means followed by the same letter (s) are not significantly different according to DNMRT ($p \leq 0.05$)

significant variation within the leaf Zn concentrations between the two locations ($p \leq 0.05$). However, the genotypes and genotype x environment interactions were not statistically different (Table 5).

The differences in Fe and Zn concentrations between cultivars within a location as well as between locations suggest the existence of a genotype x location interaction.

Table 5: Error mean square for combined analysis of variance for Fe and Zn

Parameter	Genotypes (G)	Locations (E)	Genotypes x Locations (GxE)
Iron in leaves	32987.712***	149597.317*	32987.712NS
Iron in seeds	418.950NS	665.540NS	418.950NS
Zinc in leaves	19.201NS	49.523*	19.201NS
Zinc in seeds	34.282*	55.930NS	34.282NS

NS: Not significant, *, **Level of significance at 0.05 and 0.01, respectively

The location (environment) effect and the genotype x environment interaction were significant ($p \leq 0.05$). Therefore, superiority of a genotype is clearly conditioned by the environment and to the genotype x environment interaction (G x E), which influences the selection of elite cultivars adapted to wider regions. The significant genotype x location interaction revealed the existence of genetic differences among the 20 genotypes assessed. Furthermore, the differences in both Fe and Zn among genotypes at different locations demonstrates that the environment influences the concentration of Fe and Zn in bean leaves and seeds. Differences in Fe and Zn concentrations found in each genotype, within and between locations, suggest that there is a variety difference in the uptake and partitioning of nutrients in common beans. This is in agreement with studies by De Arunjo *et al.* (2003) who observed that no single genotype showed stability for all of the characteristics studied under different environments. The mean seed concentrations of Fe (57.4 ppm) and Zn (23.0 ppm) observed in the present study are very similar to those published previously for Fe and slightly higher than Zn concentrations reported by other workers. For example, a field study in Ethiopia involving eight genotypes of the common bean showed a mean concentration of Fe of 64.4 ppm; in contrast, the mean concentration of Zn was as low as 21.7 ppm (Shimelis and Rakshit, 2005). Moreover, House *et al.* (2002) reported a mean concentration of Fe of 73 ppm in 10 genotypes of the common bean grown in Mexico. Therefore, variations in Fe and Zn concentrations may be attributed to the genetic background of the genotypes and the environments in which they are grown.

The concentrations of Fe and Zn in seeds from the genotypes used in this study suggest that there may be environmental effects on these genotypes. These differences pose a challenge in selecting genotypes with high and stable concentrations of Fe and Zn in the seeds. These observations are supported by the findings by Gregorio (2002), where the interaction effect between genotypes and the environment was significant for Fe and Zn. These results indicate that both the level and stability of Fe and Zn in the seeds differ among genotypes (Mmbag *et al.*, 1990; De Arunjo *et al.*, 2003). Similarly, studies by Gregorio (2002) and Moraghan and Grafton (2001) showed that some genotypes had a relatively low

concentration of Fe and Zn in the seeds regardless of environment while others had relatively high concentrations of these minerals regardless of environment. In other studies, both the environment and the genotype affected the Fe and Zn concentrations in common bean seeds (Moraghan *et al*., 2002).

The relationship of Fe and Zn in the yield components of the common bean: The concentrations of Fe and Zn in the leaves of common beans were strongly interdependent ($r = 0.507$; $p \leq 0.001$) (Table 6). The concentrations of Fe and Zn in the seeds were negatively and positively related to yield, respectively. The concentration of Fe in seeds was positively correlated to 100 seed weight. However, the concentrations of Fe and Zn in leaves were negatively correlated with 100 seed weight. These observations are in agreement with earlier observations by Moraghan and Grafton (2001), in which concentrations of Fe and Zn in the seeds did not correlate with 100 seed weight. However, the concentrations of Fe and Zn in the leaves did positively correlate with yield. These results suggest that a negative linkage does not exist between seed yield and Fe and Zn concentrations in seeds, meaning that it is possible to increase both yield and Fe and Zn concentrations in seeds in the same genotypes.

A positive and significant correlation coefficient of 0.495 ($p \leq 0.05$) between Fe and Zn concentrations in the seeds was observed in this study. The observed relationship of Fe and Zn concentrations in seeds are in agreement with those reported in emmer wheat (Cakmark *et al*., 2004), pigeon pea (Hogh-Jensen *et al*., 2006) and common beans (De Arunjo *et al*., 2003). The correlation between Fe and Zn concentration in seeds is an important feature for understanding the behavior of traits and is of value for selecting desired traits in a breeding program. Significant, positive correlations between the Fe and Zn concentrations in seeds and leaves suggest that selecting bean seeds with high concentrations of either Zn or Fe may increase the amount of both elements (House *et al*., 2002).

Number of days to 50% flowering and 85% maturity: The genotypes tested had significant differences in the number of days required to reach 50% flowering and 85% maturity at both locations ($p \leq 0.05$). The Lingot Blanc genotype showed the earliest flowering at both Morogoro and Madiira-Arusha, while the Uyole 84 and Uyole 98 genotypes had the latest flowering at both locations (Table 7, 8). There were significant differences in the

Table 6: Simple correlation coefficients among variables in common bean

Variables	Leaf Iron	Leaf zinc	Seed iron	Seed zinc
Leaf zinc	0.507***			
Seed iron	-0.181	-0.137		
Seed zinc	0.179*	0.307	0.495*	
100 seed weight	-0.338	-0.126	0.148	-0.387
Seed yield	0.133	0.318	-0.184	0.382

*, **, ***Level of significance at 0.05, 0.01 and 0.001, respectively

Table 7: Yield and yield components of bean genotypes grown at SUA-Morogoro

Genotypes	Days to 50% flowering	Days to 85% maturity	No. of seed pod^{-1}	No. of pods plant^{-1}	100 seed weight (g)
Sua90	32.7cd	69.7def	4.7ab	20.7bcde	28.3gh
Jesca	30.3cd	69.3def	3.0e	12.7de	50.8ab
Rojo	32.3cd	71.7cdef	4.0bcd	13.7de	46.1abc
Lingot blanc	30.0 d	69.0ef	3.0e	13.7de	48.0abc
Canadian wonder	32.3cd	76.3c	3.7cde	16.0cde	35.9efg
Pesa	31.0cd	72.0cdef	3.0e	15.0cde	42.2cde
Lyamungo 90	32.3cd	68.3f	3.3de	15.0cde	52.5a
Mwanga Chuchu	39.3a	83.0a	3.7cde	23.3bcd	20.4i
Mshindi	31.3cd	69.7def	3.0e	15.7cde	38.1def
Wanja	30.7cd	69.3def	3.0e	10.7e	48.3abc
Ranjonomby	31.0cd	69.0ef	3.3de	22.3bcd	44.2bcd
Selian 97	33.3cd	72.0cdef	3.3de	7.7bcde	43.0bcde
Uyole 96	33.7cd	75.3cd	4.3bc	0.3bcde	31.7fg
Bwana Shamba	33.0cd	72.3cdef	3.0e	22.3bcd	48.0abc
Rosekoko	32.0cd	69.0ef	3.7cde	9.3bcde	46.9abc
Uyole 90	38.3ab	77.3bc	5.3a	37.7a	31.0fgh
Red Wolaita	40.0a	82.3ab	3.3de	25.7bc	23.8hi
Uyole 98	33.7cd	76.3c	3.7cde	39.0a	35.3efg
Uyole 94	34.7bc	75.0cde	4.0bcd	25.3bc	44.6abcd
Uyole 84	40.3a	84.7a	3.7cde	27.3b	36.8def
Mean	33.6	73.6	3.6	20.7	39.8
CV%	6.7	4.4	14.0	27.8	10.7
SE±	1.3	1.9	0.3	3.3	2.5

Means followed by the same letter(s) are not significantly different according to DNMRT ($p \leq 0.05$)

Table 8: Yield and yield components of bean genotypes grown at Madiira-Arusha

Genotypes	Days to 50% flowering	Days to 85% maturity	No. of seed pod^{-1}	No. of pods plant^{1}	100 seed weight (g)
Sua90	32.3fg	70.3cd	5.3abc	13.3abcd	28.0 bcd
Jesca	34.7cde	67.0d	4.7bcd	8.7d	39.0abcd
Rojo	43.3a	71.0bcd	4.3bcd	15.3abcd	35.5abcd
Lingot Blanc	31.3g	68.3cd	4.0cd	9.3cd	47.3abc
Canadian Wonder	35.0cd	76.0b	5.7ab	10.7bcd	33.8 abcd
Pesa	32.7efg	73.0bc	4.7bcd	11.3abcd	38.7abcd
Lyamungo 90	34.0def	70.3cd	3.3d	12.7abcd	48.4ab
Mwanga Chuchu	35.3cd	81.7a	5.7ab	17.3ab	20.5d
Mshindi	33.7def	70.7bcd	4.7bcd	15.3abcd	31.7abcd
Wanja	40.7b	70.3cd	4.0cd	10.7bcd	43.5abc
Ranjonomby	40.0b	69.7cd	4.3bcd	10.0cd	35.3abcd
Selian 97	33.7def	73.7bc	5.0bc	14.3abcd	42.2abcd
Uyole 96	35.7cd	72.3bcd	4.7bcd	12.3abcd	50.0ab
Bwana Shamba	34.3cdef	73.0bc	5.3abc	12.7abcd	38.8abcd
Rosekoko	35.3cd	72.3bcd	5.0bc	13.3abcd	47.2abc
Uyole 90	36.3c	82.0a	6.7a	18.0a	25.5cd
Red Wolaita	35.3cd	81.7a	6.7a	17.0ab	29.1bcd
Uyole 98	44.7a	73.3bc	5.0bc	16.0abc	37.0abcd
Uyole 94	35.0cd	73.7bc	4.7bcd	14.7abcd	52.0a
Uyole 84	35.0cd	83.3a	5.3abc	13.7abcd	37.0abcd
Mean	35.9	73.7	5.0	13.3	38.0
CV%	3.1	3.8	15.5	25.4	9.2
SE±	0.6	1.6	0.4	2.0	2.0

Means followed by the same letter(s) are not significantly different according to DNMRT ($p \leq 0.05$)

number of days required to reach 50% flowering among genotypes when compared across locations ($p \leq 0.05$). The number of days required to reach 85% maturity were independent of the time required to reach 50% flowering. Genotype Uyole 84 matured late at both locations as well as when the data were combined from both locations. There was highly significant variation in the number of days required to reach 85% maturity among the genotypes across locations ($p \leq 0.001$). These results suggest that in addition to the presence of genetic differences, the flowering duration among genotypes was also affected by the environment, possibly due to differences in the temperature of the two locations. In the warmer location (Morogoro), maturity occurred earlier compared to Arusha, which was relatively cooler. The genotype x environment interaction in the number of days required to reach 50% flowering suggests that some genotypes were poorly adapted to the low temperatures. Low temperatures retard growth and development of some common bean genotypes. The effects of low temperature have also been observed by Ohashi *et al.* (2000), in which there was decrease in growth, development and flowering duration in beans grown at low temperature. However, variation in maturity is caused by altitude and temperature and a lower altitude induces earlier flowering, while a higher altitude causes later flowering. Rutaihwa *et al.* (2004) reported that a lack of genotype x environment interaction suggests that maturity is controlled more by genetics than by the environment.

Yield characteristics: There were highly significant differences among bean genotypes in the number of seeds per pod and the number of pods per plant at both locations (Table 7 and 8; $p \leq 0.001$). At Morogoro, the number of seeds per pod varied from 3.0 to 5.3 (Table 7), while the number varied from 3.3 to 6.7 at Madiira-Arusha (Table 8). The number of pods per plant varied from 10.7 to 39.0 at Morogoro and from 8.7 to 18.0 at Madiira-Arusha. The combined analysis showed that the number of seeds per pod varied significantly among genotypes ($p \leq 0.001$), between locations ($p \leq 0.001$) and across locations ($p \leq 0.01$). With respect to locations, the genotypes varied significantly in yield characteristics among themselves ($p \leq 0.05$), which suggests that the environmental effect had a significant role in how a given variety performed. The number of seeds per pod varied from 3.3 to 6.0 and the number of pods per plant varied from 10.7 to 27.8. Variation in the number of seeds per pod and the number of pods per plant among genotypes was most likely due to less adaptability and stability. Despite the fact that the number of pods per plant and the number of seeds per pod is genotype specific, differences in moisture around the time of grain filling due to heavy and frequent rainfall at the two locations may have led to differential flower drops.

Table 9: Yield components of the bean genotypes combined over locations

Genotypes	Days to 50% flowering	Days to 85% maturity	No. of seed pod^{-1}	No. of pods plant^{-1}	100 seed weight (g)
SUA90	32.5cde	70.0def	5.0ab	17.0bcd	28.2g
Jesca	32.5cde	68.2f	3.8bcd	10.7d	44.9abcd
Rojo	37.8ab	71.3cdef	4.2bcd	14.5bcd	40.8cdef
Lingot Blanc	30.7c	68.7ef	3.5cd	11.5cd	47.6abc
Canadian Wonder	33.7cde	76.2bc	4.6bc	13.3bcd	34.8f
Pesa	31.8de	72.5cdef	3.8bcd	13.2bcd	40.4cdef
Lyamungo 90	33.2cde	69.3def	3.3d	13.8bcd	50.4a
Mwanga Chuchu	37.3ab	82.3a	4.6bc	20.3abc	20.4h
Mshindi	32.5cde	70.2def	3.8bcd	15.5bcd	34.9f
Wanja	35.7bc	69.8def	3.5cd	10.7d	45.9abcd
Ranjonomby	35.7bc	69.3def	3.8bcd	16.2bcd	39.7def
Selian 97	33.5cde	72.8cdef	4.3bcd	16.0bcd	42.6bcde
Uyole 96	34.7bcd	73.8cdef	4.5bcd	16.3bcd	40.9cdef
Bwana Shamba	33.7cde	72.7cdef	4.2bcd	17.5bcd	43.4abcde
Rosekoko	33.7cde	70.7cdef	4.3bcd	16.3bcd	47.1abcd
Uyole 90	37.3ab	79.7ab	6.0a	27.8a	28.3g
Red Wolaita	37.7ab	80.0a	5.0ab	21.3ab	26.4gh
Uyole 98	39.2a	74.8bcd	4.3bcd	27.5a	36.1ef
Uyole 94	34.8bcd	74.3bcde	4.3bcd	20.0abc	48.3ab
Uyole 84	37.7ab	84.0a	4.5bcd	20.5abc	36.9ef
Mean	34.8	73.7	4.3	17.0	38.9
CV%	5.2	4.1	15.2	27.3	10.0
SE±	1.0	1.7	0.4	2.7	2.0

Means followed by the same letter (s) are not significantly different according to DNMRT ($p \leq 0.05$)

The genotypes significantly differed in their 100 seed weight at both Morogoro and Madiira-Arusha (Table 7, 8, $p \leq 0.05$). The combined analysis revealed that there were differences in genotype x environment interaction for this trait (Table 9; $p \leq 0.001$). Lyamungu 90 had the largest 100 seed weight and Mwanga Chuchu had the lowest 100 seed weight at both locations. Lyamungu 90 and Uyole 94 produced the largest seeds in Morogoro and Madiira-Arusha, respectively. These results are in agreement with those reported by Mduruma and Nchimbi (1991), where they showed differences in 100 seed weight among genotypes. In addition, the results indicate the presence of appreciable genetic variation for seed yield and yield characteristics among the common bean genotypes. Genetic variation in similar traits among bean genotypes in breeding populations has been reported by Mduruma and Nchimbi (1991). The differences in 100 seed weight among genotypes grown over different locations also indicates that the environmental factors were different. Seed size is an important characteristic in bean breeding, since larger seeds have higher consumer acceptance and command higher market prices than smaller seeds.

CONCLUSION AND RECOMMENDATIONS

This study has shown the existence of genetic variability effects on Fe and Zn concentrations in bean germplasms and suggests that there is a great potential for exploiting genetic variation without imparting a negative effect on the yield. Therefore, breeding for increased micronutrient concentrations in seeds will not cause a negative effect on the yield. In general, yield components of the studied genotypes were found to be highly influenced by environmental differences. These results imply that breeding and selection of micronutrients should be specific to the growing location. The data presented in this study will facilitate programs that may develop cultivars of beans with high yields that are significantly enriched in bioavailable Fe and Zn concentrations. The positive and highly significant correlation between the Fe and Zn concentrations in the leaves as well as the seeds suggests that genetic factors that increase Fe concentration are co-segregating with genetic factors that increase Zn concentration. These results suggest that incorporation of one of these nutrients in a breeding program will not be at the expense of the other.

The Fe and Zn concentrations among genotypes grown at two different locations were different. These data show that testing genotypes grown in different environments is very important for the development and selection of genotypes that have relatively stable concentrations of Fe and Zn in the seeds. These data also emphasize that both the genotype and environment have effects on the Fe and Zn concentrations in common bean seeds. We have found that the leaves of the common bean contain a higher than average concentration of Fe (310.0 ppm) and a moderate concentration of Zn (28.0 ppm), suggesting that these bean genotypes can be promoted as a source of Fe and Zn micronutrients in human diets, especially in developing countries. For example, in southern Tanzania, beans are commonly eaten as a source of vegetables and therefore the genotypes that have high levels of these minerals could be introduced into these areas.

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